SEGMENTAL LOSS OF LONG BONES TREATED BY ILIZAROV RING FIXATION

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BONAFIDE CERTIFICATE

This is to certify that this dissertation entitled **"SEGMENTAL LOSS OF LONG BONES TREATED BY ILIZAROV RING FIXATION"** is the bonafide work done by **DR. MUBARAK BASHA.I.** under my direct guidance and supervision in the Department of Orthopedic Surgery, Madras Medical College, Chennai-3 during his period of study from March 2004 - October 2006.

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CONTENTS

INTRODUCTION

Bone loss management of long bones is a challenge to any orthopaedic surgeon. In many cases it may be associated with sepsis, shortening, deformity, non-union etc., and complicate the situation. In the past many techniques were used to manage this clinical problem and mostly ended in amputations. A breakthrough technique invented by Prof. Ilizarov using his unique ring fixator addresses all the above mentioned complications simultaneously.

The history of orthopaedics has many milestones based on different new principles in patient management to relieve the sufferings due to many diverse orthopaedic problems. Thomas splint for femur fracture, Kuntcher's intramedullary nail for femur fracture, John Charnley's principles of low friction arthroplasty, and Rigid fixation of AO group are few of them.

In patients with bone loss initial management like fracture stabilization and primary soft tissue cover can be managed extremely well with modern techniques, the problems of subsequent bridging or regenerating areas of skeletal loss with viable bone while maintaining limb length and alignment for satisfactory function remains a substantial challenge to orthopaedic surgeon.

In cases of trauma, bone loss can occur at the time of injury or during subsequent debridement. The decision to salvage the limb demands considerable experience. A recent multicentric prospective evaluation[6] was not able to validate the clinical usefulness of any of the lower extremity injury severity scores like MESS (mangled extremity severity score), PSI (predictive salvage index), LSI(limb salvage index), NISSSA (nerve injury, ischemia, soft tissue injury, skeletal injury, shock, age), or HFA 97 (Hannover fracture scale) etc. in general, segmental defects more than 2 cm are unlikely to heal spontaneously with skeletal stabilization alone.

The following options are available for management of bone loss,

PRIMARY PROCEDURES:

1] Intramedullary nailing,

2] Plating,

3] Uniaxial / Biaxial external fixator,

4] Circular external fixator,

5] Free fibular graft,

6] Allograft,

7] Articular allograft and,

8] Tibial synostosis.

ADJUNCTIVE PROCEDURES:

1] Autogenic bone graft,

2] Osteogenic agents,

3] Osteoinductive agents (BMP-bone morphogenic protein like),

4] Osteoconductive agents (calcium phosphate cements),

5] Bone shortening / lengthening and,

6] Bone transport.

The same options are available for bone defects following tumor resections, infections, congenital conditions, and post infective sequealae.

Even though each method has its own advantages and disadvantages, Ilizarov's modular circular fixator is a versatile technique which can be used in diversity of problems simultaneously like sepsis control in bone, bone transport in bone loss, metaphyseal or diaphyseal fracture stabilization, to lengthen or shorten bone, to stimulate bone growth and healing by compression and distraction, and to correct angular and rotational deformities.

In India, Road traffic accidents and other accidental injuries are common presenting with severe soft tissue injuries with or without skeletal defects. Multiple orthopaedic surgeries with implants in presence of infections burden the patients economically and morally. Ilizarov ring fixator is a good option for these kinds of fractures with good results when compared to other methods of treatment and also considerably reducing the economical burden.

AIM OF THE STUDY

1. To analyse the effect of distraction osteogenesis in cases of segmental bone loss due to
    - Trauma
    - Tumors and

- Post Infective Sequealae.

2. To establish suitable protocols in the management of segmental bone loss using Ilizarov ring fixator.

LITERATURE REVIEW

HISTORICAL REVIEW

Limb length discrepancy was initially managed by shortening the normal limb by old surgeons like Rizzoli in Italy, Heine in Germany.

1905, Codivilla , Lambert , Steinman and Hey Grooves attempted limb lengthening by double transfixation method.

Vittorio Putty tried limb lengthening by a special apparatus with two large pins and a telescoping rod called ‘Osteon’.

1905, Codivilla of Bologna published, “to accomplish elongation of a lower extremity which was abnormally short as a result of injury, disease or malformation” by his own method by calcaneal pin traction and successive oblique osteotomies in early 1900.Freiberg also used the same method.

1913, Magnussan performed a ‘Z’ lengthening of tibia, with traction and counter traction. Many patients underwent shock and one died. Ombredane reported lengthening of femur by this technique in a case of poliomyelitis.

1929, Jones and Lovet described a technique with ‘Z’ osteotomy of femur, manual distraction of fragments using Putti’s apparatus and fixation of fragments using Kangaroo’s tendon.

1927, Abbots method became the standard in US. He did lengthening of TA, osteotomy of fibula, applied one proximal and one distal pin in tibia followed by application of distraction apparatus.
1929, His method was modified by Carrell and then by Brockway and Fowler to avoid anterior bending of the tibial fragments.

1932, Dickson, Diveley, Haboush and Finkelstein used ‘K’ wires instead of Steinmann pins. Haboush and Finkelstein were the first to describe an osteotomy of tibia without division of periosteum.

1938, Bosworth used Abbots method of lengthening but suggested that distraction should not begin until 10 days after osteotomy or atleast until there was no evidence of hematoma or infection.

1936, Compere and Sofield individually found out that all the methods are associated with appreciable number of complications.

After World War II in 1948, Allen modified Haboush apparatus and osteotomy method with stabilization of fragments using screws. His method was also associated with serious complications. Other techniques were tried to stabilize the bony fragments using slotted plates by Mc Carroll and intramedullary rods by Bost and Larsen in 1956.

1952, Anderson introduced his method in 1952, by creating tibiofibular synostosis and then tibial lengthening was performed. This technique was modified in 1967 by Coleman, Noonan, Gross and Mitchell in order to achieve lengthening in one operation. In 1959, Agerholm described a zigzag tibial osteotomy that gave more stability. In 1968, Kawamura ensured that only the cortex was divided, there by preventing nutrient artery injury.

Currently there are three biological methods of filling the distraction gap with bone,

- Wagner's method(1977) with monolateral fixator and open mid diaphyseal osteotomy
- Wassertein's method (1988) with cortical allograft. Open osteotomy over IM nail
- Ilizarov's method (1951) with circular fixator precut-subperiosteal corticotomy and distraction osteogenesis.

Ilizarov pioneered the biology of bone and soft tissue regeneration and relies on the consolidation of regenerate new bone. He attempted to preserve both periosteum and endosteum. His circular fixator, which uses crossed 'K' wires for fixation is extremely modular, allowing for simultaneous correction of multiplanar and multidirectional deformities.

DeBastiani et al (1986), have applied Ilizarov principles using a monolateral fixator that allows axial dynamization. While Ilizarov started distraction in 5 to 7 days DeBastiani et al started at 14 days to allow for increased callus formation. This has been termed 'CALLOTASIS'.

Charles.T.Price et al(1990)[10] reported this method to be simple, safe and well tolerated by children and adolescents with moderate limb length discrepancy. But using this method for large defects and for adults was not supported by these authors.

Dror Paley (1990) divided the difficulties during limb lengthening as problems, obstacles and complications. He considered all intraoperative injuries, problems that were not solved before the end of treatment were considered true complications. The complications included, muscle contractures, joint luxations, axial deviation, neurologic injuries, vascular injury, premature consolidation, delayed consolidation, non-union, pin-site problems and hardware failure. Late complications included, loss of length, late bowing, refracture and joint stiffness. Pain and difficult sleep were other in prolonged cases.

COMPONENTS AND INSTRUMENTS OF ILIZAROV APPARATUS

"The Ilizarov fixator is a device which works as a compression and distraction apparatus. The frame of the fixator can be assembled in almost any unlimited number of variations and combinations depending on the task at hand. It is no surprise that this system has been called as a 'Human Erector'"

DROR PALEY.

The Ilizarov apparatus has two types of components, primary and secondary. Primary components are the standard parts that connect the skeleton to the frame such as transosseous wires, rings and wire fixation bolts. Secondary components are the parts used to construct the frame of the apparatus such as threaded rods, telescopic rods, connecting plates, hinges, posts, nuts, bolts and various wrenches.

RINGS:

The Ilizarov ring serves 3 main functions,

1) Supports ‘K’ wires and half pins,
2) Two or more rings connected form a frame of the apparatus,
3) Bear supplementary parts of the frame necessary for dynamic bone treatment.

Half rings:

There are 12 sizes of rings with increasing inner diameter in mm from 80 to 240 mm. They have 18 to 28 holes depending on the size of the ring. The hole is 8 mm in diameter and placed 4mm apart from each other.

Full rings:

The same size rings are available. Full ring has 6 holes more than same sized half ring. The advantages of full ring are they are lighter in weight and they have more holes that can be used for different purposes. The disadvantages of full rings are they need to be placed in position before any wire is passed and if fir any cause a ring has to be removed it cannot be removed before the other rings.

Five-eighths ring;

In this three eighth of the ring is open which has the advantage of fixing near the joints to allow movements with more stability than a half ring. There is more room for extra ‘K’wire placement. It can be used for wound management and plastic procedures like flap cover etc,. They are available in all sizes as half Rings.

Omega ring:

This has similar configuration as 5/8 ring with the ends curved outside. This fits well around the shoulder and exclusively used for that. Both 5/8 ring and omega rings are not as strong as connected half rings.

ARCHES:

In the original Ilizarov set there were large semicircular arches with wide walls and double rows of holes. These were usually used for proximal; femur fixation with atleast 3 ‘K’ wires at the level of lesser trochanter endangering sciatic nerve. Dr. Catgni and Cattaneo modified the arch with 90^0 and 120^0 arch with introduction of 2 or 3 half pins instead of wires, through the lateral and anterior cortex which do not come close to the sciatic nerve.

BOLTS AND NUTS:

Bolts:

They have threaded leg 6 mm in diameter with a pitch equal to 1mm between each thread and a standard 10 mm hexagonal head, 4mm thick with different lengths of 10mm, 16mm and 30mm with each type with different purpose. 10 mm bolts are short and used for connecting the threaded sockets and bushings to the rings or connecting plates and for fastening the rods and half pins through the apertures of the socket, bushing and Ilizarov telescopic rod. 16 mm bolts are the most important that they connect two parts and leave enough space to tighten the nut. They are used to connect all main parts. 30 mm bolts are used to connect 3 or more parts.

Nuts:

This is the smallest component of the set with 10 mm diameter. They are in 3 sizes, full (6mm), three quarter (5mm) and half (3mm). Nuts serve multiple purposes in an assembly,

1) Tighten the connecting bolt,
2) Stabilize the connecting rod,
3) Tighten the wire fixation bolt,
4) Acts as a driven force in a distraction or
   Compression assembly.
5) To lock the socket or bushing into a threaded rod,
6) Affix the pulling wire of a distraction device,
7) Affix fixed positions of a male support.
8) To secure hinge clearance
9) Secure a gap on the threaded rod.

A 5mm nut is most widely used in all frame constructions. In general 5mm nuts are convenient for frame stabilization and 6mm nuts for compression and distraction assembly. 3mm nut is used usually as a supplementary one.

There are seven types of ring connectors in the Ilizarov set,

1) Threaded rods,
2) Partially threaded rods,
3) Telescopic rods,
4) Connecting plates,
5) Graduated telescopic rods,
6) Threaded sockets,
7) And oblique support connections.

The first five are in the original set and the last two were added by Italian Orthopaedic group, and ASAMI (the association the study and application of the methods of Ilizarov)

RODS:

These are the main types of connector in the Ilizarov system. They are 6mm in diameter with 10 different lengths, 60mm to 400mm with same pitch of 1mm. These rods have high strength characteristics for axial loading. Biomechanically 4 threaded rods affixed at equal interval from each other with distance between two neighboring rings not greater than the diameter of the ring give maximum stability to the frame. The slotted cannulated rods can be used as pulling devices. Partially threaded rods have a unthreaded surface in the middle section over which a telescopic rod can be used.

Telescopic rods are the mainstay of ring connection in the original Ilizarov set. They are used to connect arches and rings and are significantly stiffer than threaded rods.

Graduated telescopic rod is an invention of ASAMI, Italy and is included in the complete Ilizarov set. This has a lock which gets locked by itself with one quarter turn ie, 0.25 mm. To turn the device beyond 0.25 mm the safety lever should be released. So, this is a user friendly device, with redundant safety features like, automatic locking, audible click with each turn, and visual references on its square surface.

CONNECTION PLATES:

They are helpful in

1) Reinforcing the frame,
2) To extend the main frame construct,
3) To connect two or more components on different planes.

There are 5 types of connection plates,

1) Short connection plate – for extension of frame construct,

2) Long connection plate – for reinforcement of large frame,
3) Connection plate with threaded end – as along supporting plate,
4) Twisted connection plate – to connect a horizontal to vertical plane plate,
5) Curved connection plate – to increase the circumference of the ring.

THREADED SOCKETS AND BUSHING:

Threaded rods can be reinforced and lengthened by these two types of connectors. These connectors can be used for attachment of additional frame components.

SUPPORTS AND POSTS:

Male support has a 13 mm long standard threaded leg protruding from the butt end which serves as a connection to other components. Female post has 10 mm deep threaded hole at the butt end which serves to connect bolts and rods.

WASHERS:

Washers, although they may seem inconsequential, fill the space between the various parts and the rings provide lock tight fastening. They have 7mm hole in center. There are six types of washers,

1) 1.5mm

2) 2mm,

3) 3mm

4) 4mm

5) Conical washer couple,

WRENCHES:

They are the most important instruments that are handled in day to day adjustments and during surgery. They are important for tightening nut and bolt and nut ring tightening. Fastening must always be done with two wrenches simultaneously. One wrench is attached to static part and another to the part to be tightened. This maneuver makes it much easier to produce the necessary tightening force as much as 200kg.

HALF HINGES:

Half hinges when connected to each other, allow parts to be situated at an angle (loped) to each other. There are standard half hinges and small half hinges. Two small half hinges when connected form a low profile hinge.

The male half hinge has a standard leg protruding from the base. This leg connects it to other components. The female half hinge has a threaded hole at the base which connects it to a bolt or rod.

WIRES:

In essence, the wire is the important part of the Ilizarov apparatus that determines how the treatment proceeds and the result follows. Dr. Ilizarov began his pioneering clinical research with Kirschner wire, which has the following important advantages.

When drilled into tissue, it destroys the compact bone and the marrow very little. If tensioned, properly, it dampens vibration and prevents soft tissue and bony destruction because of its elasticity. After removal, the penetration holes are very small.

Its small diameter hole permits minimum external contamination. (What the wire lacks in comparison with the pin is stiffness).

Dr.Ilizarov modified the original K – wires for use with his apparatus. A special manufacturing process results in stainless steel with critical hardness and electricity.

In the method of Ilizarov, three types of wires are used (in 1.5 & 1.8 mm diameters).

Ilizarov wire with Bayonet Point (for cortical bone)

The bayonet point passes more easily through the diaphyseal cortex, causing less heating of the bone and soft tissues. It Produces a hole of a diameter slightly larger than that of the wire and there by results in a slightly reduced friction fix to the bone. The bayonet tip is used in the diaphysis, where the disadvantage of the reduced friction fix is balanced by greater loss of penetration.

Ilizarov wire with Trocar Point (for cancellous bone)

The trocar point permits better directional control when drilling across primarily cancellous bone, such as metaphyseal or epiphyseal segments. It makes a hole having exactly the same diameter as the wire, giving it a significant hold on the bone.

Wire with a Stopper (Olive wire)

Olive or Stopper wire with a support bead provides many special functions like interfragmentary compression, increasing stability of the construct, gradual distraction or translation of bone fragments.

<u>WIRE TENSIONER:</u>

The tensioner is a very important instrument which allows us to tension the wires to an exact force, improving stability of the entire bone-frame construct. The quality of bone healing and/or bone regenerate development depends on the strength of wire tension.

1. Simple wire tensioner (Original Ilizarov wire tensioner)

The technique of tensioning with the original Ilizarov tensioner involves first fixing the wire to the ring with a bolt. The tensioner is then fixed to the ring to keep it from sliding about the ring. Turning of the wing-nut clock wise applies tension to the wire. As inconsistent tension and extra bolt tightening are required, it is preferable to use dynamometer.

2. Dynamometric Wire Tensioner

The parts of the dynamometer are – handled for applying tension (turns), dynamometer scale from 50 to 130 kg, fixed jaw and mobile jaw. The wires can be retensioned during the treatment of the patient.

The exact strength of tensioning depends on :

* Weight of the patient (small child versus large adult).
* Local bone quality (Osteoporosis versus normal bone).
* Functional wire loading (Stabilization versus distraction compression).
* Local frame construction (half ring versus full ring; offset versus main ring wire).
* The wires should be tensioned with 50 to 70 kg.

Suggested tension strengths are as follows

* Wire on half-ring -50 to 70 kg.

* Offset (drop) wire, depending on size of the supporting post – 50 to 80 kg.
* Single wire on a ring – upto 100 kg.
* 2to3 wires on a ring for a young patient–110 Kg for each wire.
* 2 to 3 wires on a ring for an adult patient –120 to 130 kg for each wire.
* Wire with an Olive stopper – 100 to 110 kg.
* Wires with Olive stoppers used for interfragmentary compression, depending on bone condition – 50 kg.

The clinical signs of a decrease in tension strength are pain and skin irritation at the wire site. Roentegenographic signs of an increase in tension strength appear due to concave wires bending with compression and convex wires bending with distraction of the bone fragments.

WIRE FIXATION BOLTS:

The original bolts had a flat surface to fasten the wires to the ring. Now two special bolts cannulated and slotted wire fixation bolts are available to maintain strong dome fixation. The range of stiffness is between 200 – 300 kg. As a general rule 1.5 mm wires are more securely fixed with cannulated bolt and the 1.8 mm wire with slotted bolt.

WIRE FIXATION BUCKLES:

They are similar to wire fixation bolts in function with added advantage that they can be used in ring locations where there are no accessible holes. They are fixed to the ring’s flat surface but not to the ring holes. They are of two types, dual sided wire fixation buckles and the detachable wire fixation buckle. The advantage of detachable buckle is that it can be assembled and used at any ring position without being placed in advance.

OTHER COMPONENTS:

Half pins, half pin fixation bolts and rancho cubes are other important components in Ilizarov system.

BIOMECHANICS OF RING FIXATOR

Ilizarov’s fixator comprises of a modular ring fixator which uses smooth, thin 1.5 and 1.8 ‘K’ wires for multilevel, multiplanar and multidirectional transosseous fixation of fractures.

The first fundamental characteristic of this apparatus concerns the type of fixation which is called solid-elastic. The Ilizarov fixator is about 25% stiff as uniplanar and biplanar fixator in the axial direction while maintaining approximately equal stiffness to torsional and bending loads. These mechanical characteristics allow the beneficial effects of axial micromotion without the deleterious effects of torsional and translational shear.

The basic function of the Ilizarov fixator is to hold the bony fragments in alignment, while allowing axial dynamization at the fracture site. Goodship[17], demonstrated that induced axial micromotion at the fracture site can accelerate fracture healing.

These mechanical characteristics make Ilizarov fixator to get it apart significantly from other systems of external fixator. The three theoretical and biomechanical foundations of Ilizarov method are,

a) Minimal damage to vascularity,
b) Elastic stabilization of fracture site,
c) Immediate resumption to function.

Biomechanics of Ilizarov fixator has been extensively studied clinically and experimentally by G.A. Ilizarov, B. Flemming, Dror Paley, M. Pope[14] and many others.

The advantages of Ilizarov fixator are as,

1) Allows micromotion which is conductive to healing of fracture,
2) Very minimal soft tissue damage,
3) Axial dynamization at fracture site,
4) Less pin tract infection,
5) Three dimensional correction intra op and post op possible,
6) Capability of mechanical diversity.

The disadvantages include,

1) Transfixation of soft tissues,
2) Bulky apparatus,
3) Time consuming,
4) Steep learning curve,
5) Poor patient compliance till they understand the process.

Flemming[14] et al., compared the stiffness profiles of several conventional cantilever fixators with five configurations of the Ilizarov circular, multiplanar fixator

i. Ilizarov 90°/90° centered IL_1.
ii. Ilizarov 45°/130° centered IL_2.
iii. Ilizarov 90°/90° off-centered 90 Kg tensioncentered IL_3.
iv. Ilizarov 90°/90° off-centered 130 Kg tensioncentered IL_4.
v. Ilizarov 90°/90° off-centered 130 Kg tensioncentered IL_5 (Ilizarov using olive wires).

In the first two configurations (IL_1 and IL_2) bone was centered within the fixation rings. The wires were oriented at 90°/90° and 45°/130°. For the 90°/90° situation AP bending is the same as lateral bending. The maximum difference in stability is 45° from this position. The position was labeled as anteroposterior bending even though it represents a plane halfway between the anteroposterior and lateral planes. In the 3rd, 4th and 5th configurations (IL3, IL4 and IL_5) the bone was positioned eccentrically in the rings as it could be positioned on the tibia in vivo. The wires were tensioned to 900 or 1300 N. In IL_5, counter opposed Olive wires were used instead of instead of smooth Kirschner wires. The direction of bending was referenced by true anatomic positioning of the last three configurations.

STIFFNESS

The slope of the load deflection curve of the fixator pylon system is known as fixator stiffness. The Ilizarov was significantly less stiff than some of the unilateral fixators in lateral bending. The factors influencing stiffness are:

- In axial loading the Ilizarov configuration were about 75% less stiff on average than the uniplanar and biplanar fixators.
- Changing the pin orientation from 90° to 45°/130° decreases stiffness in anteroposterior bending but not in lateral bending, torsion or axial compression.
- Off-centering the bone was associated with a higher axial stiffness and a lower torsional stiffness than the centered configuration.
- Changing the wires to the Olive type led to significant increase in the bending, torsion and axial stiffness.
- Increasing the wire tension from 90 Kg to 130 Kg increased the bending and axial stiffness but lower the torsional stiffness.

Shear Stiffness

The ability of the fixator to resist translation shear at the fracture site is represented by the shear stiffness value for each directional load.

Axial Stiffness

The ability of the fixator to resist gap closure, (i.e. decrease in space between the bone ends) was measured as the axial stiffness.

One would want to select a fixator which demonstrated high shear stiffness and a low axial stiffness without deforming plastically. The highest shear stiffness was achieved by the IL_5.

The lowest axial stiffness without deforming plastically was again demonstrated by the Ilizarov fixator. The Ilizarov fixation possesses some of the most optimal biomechanical characteristics for fracture healing and it differs significantly from conventional large-pin fixators in that it maintains axial elasticity.

Biomechanical principles of the Ilizarov External Fixator and Technique

The Ilizarov external fixator exhibits more isotropic mechanical properties in bending, non linear axial stiffness, and the ability to readily create configurations for complex corrections.

Frederic J. Kummer describes that, for any fixator system, there are two fundamental inter-related considerations.

1. Stability : It is the ability of the fixator to maintain the necessary mechanical configuration during treatment.

2. Rigidity : It is measure of the mechanical response of the fixator, which has importance in the healing responsible.

Stability of Ilizarov external fixator depends on:

I. Extrinsic factors

They depend on

1. Biomechanics of the Wire.
2. Biomechanics of Rings.

II. Intrinsic factors

They depend on

1. Area of contact between bone ends.

2. Mechanical configuration and interlock between bone ends.
3. Tension of soft tissues surrounding bone.
4. Length of gap between bone ends.
5. Modulus of elasticity of tissue between bone ends.

BIOLOGY OF DISTRACTION OSTEOGENESIS

Distraction osteogenesis is a method of producing unlimited quantities of living bone directly from a special osteotomy called corticotomy by controlled mechanical distraction. The new bone spontaneously bridges the gap and rapidly remodels to a normal macrostructure for the local bone.

Ilizarov's modular ring fixator can direct the new bone formation in any plane as the distraction osteogenesis always follows the vector of applied force. Ilizarov has postulated that 4 factors are critical for osteogenesis, such as

Stability of fixation

The energy of osteotomy

The rate &

The rhythm.

This process can regenerate complete vital bone, capable of bearing load at about 1 cm of bone length per month in children and 1cm per 2 months in adults.

DEFINITIONS:

Distraction osteogenesis means new bone formation between vascularised bone surfaces, separated by gradual distraction, most commonly, the bone is separated by a corticotomy and then distracted at a rate of 1mm per day divided into a rhythm of 0.25mm four times a day, following a latency of 5 days.

CORTICOTOMY: It is a low energy osteotomy of the cortex preserving local blood supply to both periosteum and medullary canal.

LATENCY: It is the period of time after a corticotomy before initiating distraction.

RATE: It is the number of mm per day at which bone surfaces are distracted apart.

RHYTHM: It is the number of distractions per day in equally divided increments that total the rate.

TRANSFORMATION OSTEOGENESIS: Means the conversion of non-osseous interposition (fibro cartilage in non-unions, synovial cavities in pseudoarthrosis, or muscle in delayed unions) into normal bone by combined compression and distraction force, sometimes augmented by a nearby corticotomy.

BONE TRANSPORTATION: Means the regeneration of intercalary bone defects by combined distraction and transformation osteogenesis.

HEALING INDEX: Means the number of months from operation to full unaided weight bearing for each cm of new bone length.

ANATOMY

Understanding the anatomy is the most important aspect of any successful surgery. Transfixing wires endanger neurovascular structures if inserted without regard to cross sectional anatomy.

FEMUR:

When inserting wires into the femur, there are many anatomical factors to be considered,

The bulk of soft tissues,

Thick neurovascular bundle,

The sciatic nerve.

Posterior aspect of thigh has bulky hamstrings and anterior quadriceps make wire insertion difficult. Anteriorly superficial femoral vessels can be damaged if attention is not paid. The sciatic nerve prevents anteroposterior wire insertion, hence proximally wires have to be passed in fairly narrow angle.

TIBIA:

For simple procedures one ring with two crossed wires and a supplementary drop wire is used proximally and a similar combination is used distally. More stable configuration for a tibial mounting usually incorporates a wire that passes through the fibular head and into the tibia to prevent subluxation of the proximal tibio-fibular joint. Distally also the fibula must usually be incorporated into the configuration.

All the important anatomical structures lie anteriorly or posteriorly in the distal leg. This provides many ideal locations for the transfixation wires. When immobilizing the tibio fibular articulation the foot should be positioned in dorsiflexion during wire insertion to allow for more complete ankle movement post operatively. Fibula fixation is contra indicated at fibula neck level for fear of peroneal nerve damage.

HUMERUS:

In the proximal humerus, wires can be inserted with arm in 90 degrees in abduction and external rotation of 20 degrees. A third wire can be inserted with a drop. in distal humerus the bone flattens and widens near elbow. Hence crossed wires in axial plane is not possible. One wire from each epicondyle, exiting the humerus proximally at the medial and lateral supracondylar ridges with a third wire in the middle of supracondylar ridge gives stable fixation. Care should be taken not to transfix either the ulnar or radial nerves. After wire fixation movements of elbow should be checked to rule out entry of wires in the olecranon fossa.

When three ring construct is needed, wires should be inserted with regard for the location of the neurovascular bundles.

PHYSIOLOGY

The most important factor in successful distraction osteogenesis is the regional and local blood supply. Each column of bone is completely surrounded by large vascular sinusoids. The orderly formation of bone in distraction osteogenesis involves collagen deposition, osteoid formation, and mineralization.

PATHOPHYSIOLOGY

Certain conditions that reliably lead to poor osteogenesis are

Traumatic corticotomy,

Initial diastasis,

Excessive rate,

Sporadic rhythm,

Frame or bone- fixator instability,

Inadequate consolidation period,

Poor regional or local blood supply,

Peripheral vascular diseases.

HISTOLOGY

Histological preparations show the following sequential events in distraction osteogenesis,

During initial latency (first week): fibrin enclosed hematoma and inflammatory cell infiltrate filling the gap at the osteotomy site called fibrous interzone (FIZ)

2^{nd} week: appearance of osteoblastic cells on either side of FIZ. Initially they rest on the surface of primary bone spicules formed by fusion of collagen and matrix and eventualy become enveloped within, as the spicule is gradually enlarged by circumferential apposition of collagen and osteod. The early bone spicules are called the primary mineralization front (PMF), extending from each corticotomy surface towards the central FIZ resembling stalactites and stalagmites.

3rd week: microcolumn formation with base at the host bone surface and tip towards FIZ.

At the end of distraction the FIZ ossifies creating one zone of microcolumn formation (MCF) and completely bridging the gap, during this 6 week consolidation period.

Six weeks after the consolidation the estrogenic area remodels into cortex and medullary canal.

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METHODS OF BONE LOSS MANAGEMENT BY ILIZAROV METHOD:

For bone loss of less than 5 cm: single corticotomy and bifocal osteosynthesis. For bone loss of more than 5 cm: double corticotomy and trifocal osteosynthesis

For bone loss of more than 10 cm:

a) Double corticotomy and trifocal osteosynthesis with both internal and external bone transport.

b) Lateral bone transportation by

1] Longitudinal corticotomy of parallel bone,

2] Complete transposition of adjacent bone with double osteotomy,

3] Detachment of fibular fragment in leg.

Monofocal osteosynthesis with compression and successive distraction can also be done in cases with moderate bone loss.

CORTICOTOMY

Ilizarov concluded that preservation of endosteal tissues and vasculature, results in more rapid and reliable bone formation and consolidation. Corticotomy means a low-energy cortical osteotomy with transaction of only the bone cortex. The periosteum, the endosteum, the bone marrow with its blood supply, as well as the muscles and soft tissues surrounding the bone are maximally preserved. A Corticomy is best described as an open subperiosteal partial osteotomy of the bone cortex, followed by manual osteoclasis of the remainder of the cortical circumference.

De Bastiani and associates subsequently described an open modification of the corticotomy under direct vision. The energy used to transect the bone is an additional factor that influences the viability of the osteotomy site and its estrogenic potential. Power saws and high-speed burrs can cause thermal necrosis of the bone ends and adjacent soft tissues. Low energy alternatives include both osteotomes and the Gigli Saw. Periosteum, endosteum and cortical bone have all been shown to contribute the neo-osteogenesis, with the periosteum considered most important.

1. Classic Method

This is a percutaneous subperiosteal cortical osteotomy. This technique is performed with an osteotome in two different methods.

I. Triangular bone method – Eg, Tibial Ulnar or Radius corticotomy.

II. Round table method - E.g., Femoral or Humeral corticotomy.

2. Percutaneous Gigli saw method (for tibial corticotomy)

This method is first introduced to Dror Paley by Dr. Abdul Paktiss from Afghanistan. Paktiss passes a Gigli saw subperiosteally around the tibia. With the protection of periosteum, the bone is then transected. The advantage of this technique is that the apparatus does not need to be disconnected and no rotational osteoclasis is needed. This is especially advantageous in cases with bone defect.

The complications of corticotomy include damage to the osteogenic elements through rough surgical technique, displacement of the fragments after corticotomy and incomplete corticotomy.

RADIOLOGY OF REGENERATE

Based on clinical experience of more than 800 limb lengthening (of upto 60% of initial length), Catagni has classified different radiographic morphologies related to healing time and weight bearing capacity.

1. **Normotrophic Regeneration**

It is distinguished by early radio dense new bone formation occurring approximately 20 days after the initial operation. Definite columns of longitudinally oriented new bone appear from each corticotomy surface with a central transverse radiolucent area. The diameter of the regenerate equals to the parent bone.

2. Hypertrophic Regeneration

New bone appears on 20th day of distraction. The cross-sectional diameter of regenerated bone exceeds that of the corticotomy site. Premature consolidation is possible if distraction rate is 1 mm/day. It is usually seen in young active patients.

Hypertrophic regenerate

New bone is delayed in its radiographic appearance (not appearing by day 30). The rate of distraction is too rapid for the local biology. There are 4 types.

Type A : Spotty radio densities persist after day 50, indicating poor vascularity.

Type B : Hourglass configuration indicates that distraction rate is too fast.

Type C : Irregular regenerate bone columns may indicate instability or vascular insufficiency.

Type D : Focal failure of bone formation indicates a local vascular Injury or periosteal damage.

Hamanishi et al., classified the radiographic appearance of the distraction falls into 6 steps.

1. External : Barrel – like fusiform callus wider than the original bone.
2. Straight : Homogenous callus as wide as the original bone.
3. Attenuated : Callus just a wide as the original bone.
4. Opposite : Callus formation or maturation mainly at the opposite side of the lengthened. (This type of callus not found in limb lengthening by using external ring fixators)
5. Pillar : Poor callus only in the central portion and is looking like central pillar.
6. Agenetic : Only Sparse calcification in the lengthened gap.

Other imaging techniques for evaluation of regenerate bone are:

1. **Ultrasound evaluation**

When roentgenographic evaluation is doubtful, regenerate bone can be seen well on ultrasound[37]. Technically, a “real-time” unit is utilized in combination with a section probe. It is proved useful to place a silicone spacer between probe tip and the skin.

2. **Radionuclide evaluation**

It has been possible to follow the dynamics of regenerate bone formation and to evaluate the repair process in a quantitative fashion. It is helpful in the assessment of the degree of maturation of new bone formation.

RADIOLOGICAL MONITORING:

In each step of distraction osteogenesis radiological monitoring is mandatory to assess the progress of bone formation.

At the time of corticotomy fluoroscopic control is used for

Completeness of corticotomy,

Distraction no more than 2mm,

Angulation no more than 10- 15 deg,

Rotation no more than 20- 30 deg.

Standard radiography provides good weekly or biweekly check on the progress of the distraction gap (length and alignment).

Usually by the 3rd week, new bone mineral appears as fuzzy, radio dense columns extending from both cut surfaces towards the center. As distraction proceeds a central FIZ (fibrous interzone) appears as undulating radiolucent zone 4- 8 mm wide while more and more bone is added from each end. If the new bone appears to be bulging and FIZ narrowing, then distraction rate is accelerated. If the new bone forms as an hourglass appearance and the FIZ is widening, distraction is reduced. Ultrasound can be used to diagnose cyst formation in the gap which may require bone grafting.

During consolidation, x-rays are obtained on a monthly basis until the osteogenic area has cortex and medullary canal on orthogonal views

MATERIALS AND METHODS

This is a study to evaluate the patients with segmental loss of long bones managed by distraction osteogenesis using Ilizarov ring fixators at Government General Hospital Chennai for the period between August 2004 to October 2006.

A total of 20 patients with segmental bone loss were included in this study. Males were 15 (14 yrs – 68 yrs) with a mean age of – 34.8 yrs. Females were 5 (12 yrs -53 yrs) with a mean age of 36 yrs. 14 patients have completed the treatment. Other 6 patients have completed the bone transport and waiting for consolidation and ring removal. The follow-up period ranged from 2 ½ months to 8 months.

The etiology of bone defect was post traumatic bone loss in 13 cases, post tumour resection bone defect in 6 cases, and post infective sequealae in 1 case. 2 cases had initial treatment with ORIF, 1 with plate osteosynthesis (case no:11) and another with intramedullary interlocking nail (case no: 14) elsewhere and referred for bone loss management.

In post traumatic cases intercalary bone defect ranged from 7 cm to 15 cm with an average of 9.3cm. This bone loss includes the gap created both during trauma and subsequent wound debridement and resection of necrotic bone. In post tumour resection cases the defect ranged from 4.5cm to 20cm with an average of 10.6 cm. In post infective sequealae the bone loss was 3 cm.

Etiology	*No. of Patients*	*Percentage*
Post traumatic	13	65%
Post tumor resection	6	30%
Post infective sequelae with bone loss	1	5%

The site of bone loss was distal femoral in 5 cases, tibial in 14 and mid tibial with deformity in one case. After Ilizarov fixation 16 cases were treated by bifocal osteosynthesis and 4 cases were treated by trifocal osteosynthesis.

Method of osteosynthesis	*No. of Patients*	*Percentage*
Bifocal	16	80%
Trifocal	4	20%

The following procedures were done prior to Ilizarov fixation,

Pre Ilizarov procedures:

Biopsy in all the 6 tumour cases.

Curettage with Bone grafting in 3 cases.

Resection and external fixator application in 6 tumour cases.

SSG – 11 cases:

Flap cover – 4 cases,

ORIF with plate osteosynthesis 1 case.

ORIF with IM nail 1 case {implant exit done before Ilizarov [case no 14]}.

ORIF – IM nail 1 case { transport done over the nail [case no: 2]},

Wound debridement and external fixation in 13 post trauma cases.

Corticotomy was done along with Ilizarov fixation in 13 cases in the same sitting and as a separate procedure in other 7 cases. Corticotomy was delayed in these cases due to poor skin condition. Post corticotomy latency period (the duration between corticotomy and beginning of distraction) extended between 4 days to 17 days with an average of 11.1 days. The delay in distraction in one case (case no: 12) was due to osteoporosis. The corticotomy sites were, proximal tibial in 10 cases, proximal femoral in 1 case, distal tibial in 4 cases, proximal tibial with mid femoral in 3 cases, proximal and distal tibial in one case and proximal tibial with mid fibular in one case.

Site of corticotomy	*No. of Patients*	*Percentage*
Proximal tibial	10	50%
Proximal femoral	1	5%
Proximal tibial and mid femoral	3	15%
Distal tibial	4	20%
Proximal and distal tibial	1	5%
distal tibial and mid fibular	1	5%

The following additional procedures were done after Ilizarov fixation,

Post Ilizarov Procedures:

Bone grafting – 4 cases,

TA lengthening – 2 cases.

Pin Exchange in 2 cases.

Ring-Realignment in 9 cases,

Recorticotomy in 3 cases.

Soft tissue release in 4 cases,

Freshening of bone ends and acute docking in 3 cases.

POST-OP PROTOCOL:

Rate of Distraction

1 mm per day (0.25 mm / 4 times per day) in most of the cases. During transport in few cases the rate had to be slowed down to ½ mm per day based on regenerate formation. In one case of deformity (post infective squealed) the rate was increased to 2mm per day as the regenerate formation was faster.

Rehabilitation Therapy

- All the patients are put on foot drop splint post operatively.
- Active exercises to ankle and toes. Isometric quadriceps exercises were started.
- Non weight bearing crutch walking started after 5 days.
- 3 weeks later partial weight bearing started and the patient progressed to near full weight bearing with the help of axillary crutches depending on their pain tolerance.

Radiological Evaluation

All patients had fortnightly clinical and radiological evaluation during the distraction period. After the end of distraction, evaluation was done monthly depending on the desired objectives and patients cooperation.

Planning of Fixator Removal

1. Radiological union at non-union site and corticalisation of regenerate.
2. Clinical examining revealing
   I. No mobility on removing bars across non-union and rotating the ring.
   II. No pain or deformity on removal of tension of wire and allowing patient to walk for one week.

OBSERVATIONS

The following observations were made in this study.

- 16 cases needed bifocal osteosynthesis and 4 cases needed trifocal osteosynthesis. In cases more than 10 cm bone loss trifocal osteosynthesis by double level corticotomy accelerated the bridging the bone gap.
- The treatment period ranged from 40 weeks to 111 weeks with an average of 69 weeks.
- All the 14 cases who have completed the treatment achieved bony union.
- 3 cases had residual shortening of less than 2.5 cm.
- 2 cases had varus deformity of leg less than 7° which did not interfere with ambulatory function and 3 cases had equinus deformity which needed correction by extension of fixator(foot assembly)
- Soft tissue dystrophy with pain was present in 2 cases who had poor compliance for ambulation.
- 3 patients had persistent pedal edema at the completion of treatment.
- 2 patients had knee stiffness of which one needed extension of fixator with hinges for correction and 5 patients had ankle stiffness which were managed conservatively.
- The distraction rate had to be slowed down to 0.5 mm in 3 cases of whom one had Diabetes mellitus and another had osteoporosis.

The third one probably was due to poor local condition of the soft tissue envelope.

- One patient needed accordion maneuver to complete union.
- Three patients had failed corticotomy, the first one (case no: 3) due to irregular follow up, the next (case no: 20) due to accelerated callus formation and the third (case no: 4) probably due to improper technique.
- Pin tract infection was less in those patients who adhered to twice daily cleaning of pin sites during out patient treatment.
- Almost all the patients had pain temporarily at some time or other during the course of treatment. They were managed with analgesics and appropriate adjustments in the fixator.
- One patient [case no: 3] had angular deformity at the regenerate site which needed correction.
- The healing index in our study is 57.8 days.

ILLUSTRATIVE CASES

1. Case No: 7

Perumal 42 / M Patient had road traffic accident and sustained Grade III B compound fracture both bone right leg for which wound debridement and external fixation with AO rods done on day one. After a week necrectomy was done. After 10 days patient developed urocutaneous fistula managed by supra pubic cystostomy. SSG was done after one month. Ilizarov fixation was done at 3 months post injury.

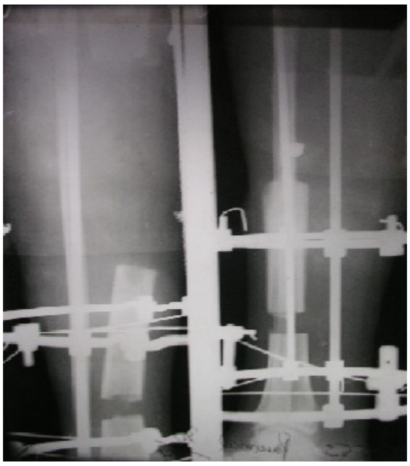
Post traumatic bone defect was 15 cm.

Post Ilizarov events:

Distal tibial corticotomy was done after 2 weeks.

Latency	- 14 days
Rate of transport	- 1 mm per day
Rhythm	- ¼ turn 6^{th} hourly
Duration of transport	- 8 months
Duration of consolidation	- 15 ½ months
Ilizarov Removal	- 25 months
Secondary procedures	- Re- alignment, ST release, necrectomy, SSG, K wire exchange .
Complications	- Grade I pin site infection.

PERUMAL



1)After Fixator Removal 2) 3 weeks post

distraction

3) After Completion of Transport 4) After Ring Removal

6) Post Ring Removal – Clinical

After fixator removal AK slab applied for 4 weeks. Partial weight bearing allowed 10 days after Ilizarov fixation. Patient tolerated full weight bearing at 4 weeks post op PTB cast applied after 4 weeks and continued for 6 weeks. Then tibial brace was applied. The bony and functional results were excellent.

2. Case No: 8

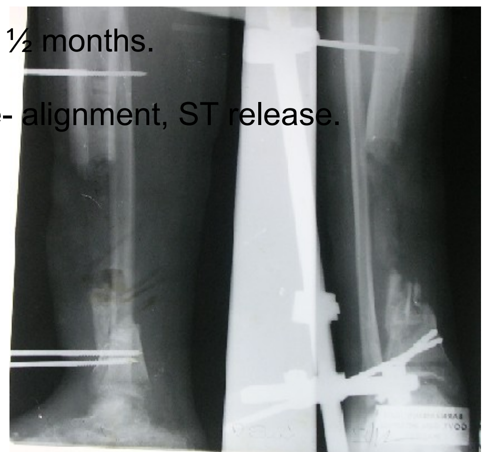
Gopuravel 19 / M Patient had road traffic accident and sustained Grade III B compound fracture both bone right leg on 28-08-04 for which wound debridement and external fixation with AO rods done on day one. SSG was done after 5 weeks. Flap cover was done at 2 ½ months. Ilizarov fixation with proximal tibial corticotomy was done at 5 months post injury after healing of soft tissues.

Post traumatic bone defect 7 ½ cm.

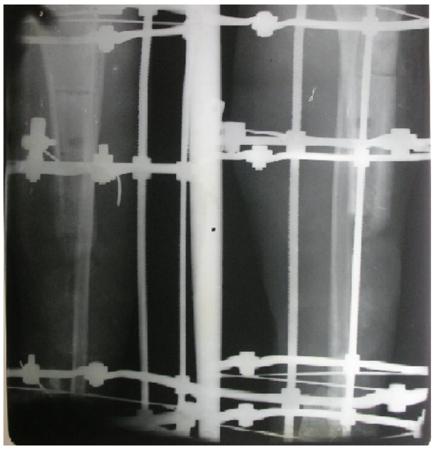
Post Ilizarov events:

Latency	- 14 days.
Rate of transport	- 1 mm per day.
Rhythm	- ¼ turn 6th hourly.
Duration of transport	- 5 ½ months.
Duration of consolidation	- 10 months.
Ilizarov Removal	- 15 ½ months.
Secondary procedures	- Re- alignment, ST release.

GOPURAVEL



1) Pre op



2) Post Necrectomy

3) Post Corticotomy

4) Post Ring Removal

5) Post Ring Removal – Clinical

Complications - Grade I pin site infection 5^0 of varus of leg, ankle stiffness.

After fixator removal AK slab applied for 4 weeks. Partial weight bearing allowed 10 days after Ilizarov fixation. Patient tolerated full weight bearing at 3 weeks post op PTB cast applied after 4 weeks and continued for 6 weeks. The bony and functional results were excellent.

3. Case No: 10

Mangalakshmi 40 / F Patient had road traffic accident and sustained Grade III B compound fracture both bone right leg for which wound debridement and external fixation with AO rods done on day one. After a week necrectomy was done. SSG was done after three weeks. Ilizarov fixation with proximal tibial corticotomy was done at 1 months post injury.

Post traumatic bone defect 5 cm.

Post Ilizarov events:

Latency	- 7 days
Rate of transport	- 1 mm per day
Rhythm	- ¼ turn 6^{th} hourly
Duration of transport	- 3 months
Duration of consolidation	- 6 ½ months
Ilizarov Removal	- 9 ½ months
Secondary procedures	- Re- alignment, necrectomy,

MANGALAKSHMI

1) Pre op

2) 3 weeks post transport

3) Completion of transport

4) Post Ring Removal

5) Post Ring Removal - Clinical

fibular osteotomy bone grafting.

Complications - Distal leg varus, pedal edema, ankle stiffness.

After fixator removal AK slab applied for 4 weeks. Partial weight bearing allowed 10 days after Ilizarov fixation. Patient tolerated full weight bearing at 4 weeks post op PTB cast applied after 4 weeks and continued for 4 weeks. The bony and functional results were excellent with good functional results.

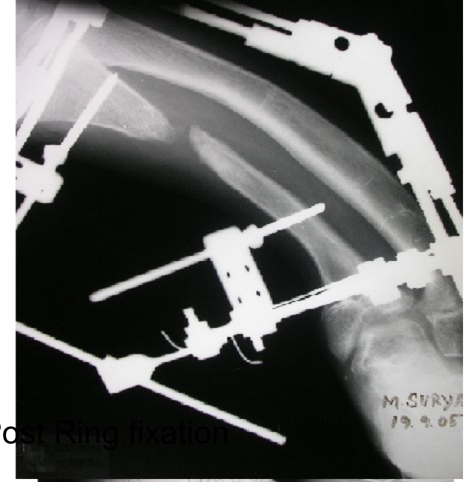
4. Case No: 20

Surya 14 / M Patient presented with progressive deformity, limp and difficult walking for 10 months. There was history of swelling over the right leg 13 years back which of treated with intra venous antibiotics for 2 weeks and the limb was splinted with pop serial casts. Other motor, mental, and developmental miles stones were normal. On examination there was varus deformity with shortening of right leg with significant limp. Right foot was in external rotation, fibula was hypertrophic alone the whole length. A bony discontinuity felt at middle third of tibia.

X-ray showed pseudarthrosis of tibia in middle third with a bone loss of 3 cm with varisation, hypertrophic fibula with ankle in vaurs, superior tibio fibular diastasis prominent distal tibial epiphysis.

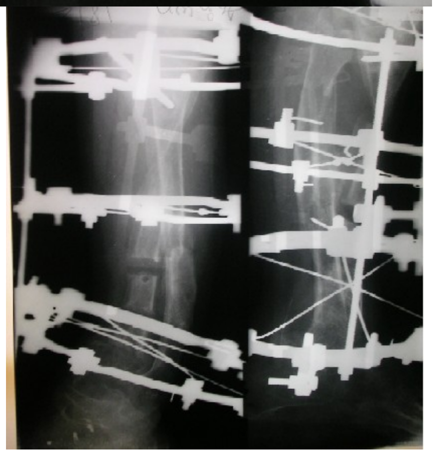
SURYA

1) Pre op



2) Post Ring fixation

3) Post Ring Fixation – Clinical



4) 2 weeks post Coricotomy

5) Post Ring Removal

6) Post Ring Removal - Clinical

Ilizarov fixation was done on 02-09-05.

Post Ilizarov events:

Latency	- 3 days.
Rate of transport	- 1 to 2 mm per day.
Rhythm	- ¼ to ½ turn 6^{th} hourly.

Duration of transport	- 2 ½ months.
Duration of consolidation	- 9 ½ months.
Ilizarov Removal	- 12 months.
Secondary procedures	- Re- alignment, recorticotomy.
Complications	- Limb length discrepancy of 3cm

After fixator removal AK slab applied for 3 weeks. Partial weight bearing allowed 10 days after Ilizarov fixation. Patient tolerated full weight bearing at 2 weeks post op. The bony and functional results were excellent.

5. Case No: 2

Raja 22 / M presented with complaints of pain and swelling of right knee for six months. On examination a swelling of 15 X 12 cm in the proximal third leg, skin over the swelling stretched with a linear surgical scar over the anteromedial aspect of leg. No dilated veins. Not warm. Tenderness over the swelling present with smooth surface and firm to hard in consistency. There was no distal neurovascular deficit.

RAJA

1) 6 weeks post transport

2) Completion of transport

3) Post Ring Fixation

5) Post Ring Removal- Clinical

4) Post Ring removal

There was previous history of surgery 3 years back details of which not known. FNAC and biopsy turned out to be Chondroblastoma.

On 13-05-2005 wide resection and knee arthrodesis done with intramedullary K nail. After 1 ½ months Ilizarov ring fixation with tibial corticotomy done.

Post resection bone defect 10 cm.

Post Ilizarov events:

Latency	- 14 days
Rate of transport	- 1 mm per day
Rhythm	- ¼ turn 6^{th} hourly
Duration of transport	- 3 ½ months
Duration of consolidation	- 5 ½ months
Ilizarov Removal	- 9 months
Secondary procedures	- TA lengthening, ST release
Complications	- Grade I pin site infection, mild Equinus

After fixator removal AK slab applied for 4 weeks. Partial weight bearing allowed 10 days after Ilizarov fixation. Patient tolerated full weight bearing at 3 weeks post op. The bony and functional results were excellent.

RESULTS

The results were assessed according to Dror Paley's assessment criteria listed below. The results were divided into bony and functional. For bony results 4 criteria were evaluated-union, infection, and deformity and leg length discrepancy. An excellent bony result was one with union without infection, deformity less than 7 degrees and length discrepancy less than 2.5 cm. A good result was union plus any two of the other. A fair result was union plus one of the other. The poor result was non-union of re-fracture or none of the others.

In our study union was achieved in all 14 cases that have completed treatment. No cases had discharging sinus after treatment. Two cases had varus deformity of leg of less than 7 deg. 3 cases had shortening of less than 3 cm. According to the system of evaluation of bony results 10 cases had excellent, 4 had good, and 1 had poor results. None of the patients had reactivation of infection at regenerate site.

Functional results were based on 5 criteria's: Significant limp, equinus, rigidity of the ankle, soft tissue dystrophy, pain and inactivity. An excellent was active individual with none of the other four criteria's. A good result was active individual with one or two of other four criteria's. A fair result was active individual with 3 or 4 of other criteria's. An inactive individual was considered as a poor result regardless of other criteria's.

Bony results

Results	*No of patients*	*Percentage*
Excellent	10	66%
Good	4	26%
Fair	-	-
Poor	1	5%

In our study 2 cases had significant limp, 3 had equinus deformity, 2 had knee stiffness and 5 had ankle stiffness. Soft tissue dystrophy and pain was present in 2 cases. 1 patient was inactive after the treatment who is on compression assembly for union of fracture site. 3 patients had pedal edema. According to this system, excellent results in 3, Good results in 11, poor result in 1 in completed cases.

Functional results:

Results	*No of patients*	*Percentage*
Excellent	4	26%
Good	10	66%
Fair	-	-
Poor	1	5%

In spite of excellent bony result in most of the cases (10 cases) the functional results were less than that(good results in 11 cases) due to presence of other associated injuries, number of previous surgeries, muscle and scar adhesion to bone, grossly influenced the functional out come.

COMPLICATIONS

All the complications occurred in our cases were recorded as per Dror Paley's classification on complications.

Dror Paley's classification:

Problems: Difficulties that required no operative intervention

Obstacles: Difficulties that required operative intervention.

Complications: All intraoperative injuries and problems those are not resolved before the end of treatment.

Complication		
Problems	Obstacles	Complications
Axial Deviation(2)	Wire cut through(1)	Joint stiffness(7)
Poor quality regenerate(3)	Skin invagination(9)	Significant pain(2)
Transient pain (in all)		Edema(2)
Transient Edema(in all)		
Pin tract infection (8)		
Parasthesias (1)		

In our study, there were no intraoperative complications such as neurovascular damage due to pin insertion. There was no compartment syndrome due to corticotomy. The common problem encountered was pin tract infection. Four patients had grade I pin tract infection, 5 cases had grade II pin tract infection. Infection was managed with oral antibiotics and local care. Loosening of K wire was seen in 2 cases which were treated by exchange of wires. 9 cases needed realignment of the fixator due to the malalignment of bone ends. Premature consolidation of regenerate was present in one case which was managed by recorticotomy and accelerated transport. In two more cases recorticotomy was needed due to irregular follow up in one and improper technique in the other. Delayed consolidation was seen in 2 cases in one due to osteoporosis and another because of Diabetic Mellitus. 4 cases had delayed union at the regenerate docking site which was treated with bone grafting. 3 cases had equinus deformity for which closed Tendo Achilles lengthening done. 2 cases had significant limp, 2 had knee stiffness and 5 had ankle stiffness.

DISCUSSION

Reconstruction of segmental loss of long bones remains a difficult problem. We have found that the Ilizarov ring fixation to be effective in the treatment of long bone segmental loss, as it allows for the simultaneous treatment of bone loss, infection, non-union deformity, articular and limb function, weight bearing and osteoporosis.

9 of the 20 patients had pin tract problems in our study. Four had Grade I infection, five had Grade II infection. None of the patient had Grade III pin tract infections. 6 wires had to be removed and exchanged because of pin loosening and infection. Our results were compared with Dror Paley's[31] results.

Three patients develop equinus deformity of ankle during distraction and required extension of the construct across the joint and gradual stretching of the Tendo Achilles. In two cases of FFD knee, one required extension of fixator with hinge for correction, the other patient required only physiotherapy.

Two patients had persistent pedal edema even after removal of the apparatus. There were no serious neuro vascular complications.

There was delayed consolidation of regenerate requiring slowing down of the distraction rate to 0.5mm per day in two patients due to Diabetes mellitus in one case and osteoporosis in the other.

Three patients required recorticotomy following failed coticotomy due to irregular follow up in one, accelerated callus formation in the next and poor local conditions in the third. Four patients required bone grafting at the regenerate docking site for delayed union.

The results of this series were compared with Dror Paley's results in his series of 25 patients.

Pin tract infection was frequent in both series. In our series 4 patients (20%) had Grade I and 5 patients (25%) had Grade II pin site infection. Dror Paley's has reported 20% incidence of Grade I and 10% of Grade II infections, 3.5% of Grade III pin tract infection. There were no Grade III infections in our series.

There were no intra operative or post operative nerve injuries in this series, as compared to Dror Paley's series with one intra operative sensory nerve injury which had recovered fully.

There were no incomplete corticotomies in this series where as there were 3 instances of incomplete corticotomies in Dror Paley's series.

3 (16%) cases required correction of equinus deformity of ankle by extension of fixator (foot assembly) and in 2 cases (10%) of knee flexion deformity one required extension of fixator with hinges in our series. Dror Paley has reported joint contractures in 3 patients (10%), one treated non-operatively and the other two operatively.

Delayed consolidation of regenerate docking site required bone grafting in four cases (25%) in our series. Dror Paley has reported bone grafting in all his cases.

There are no serious vascular complications in our series as compared to Dror Paley's series[31].

Factors	*Dror paley et al*	*MMC study*
No. Of Cases	25	20
Age	19-62	12-68
Size of Bone Defect	1 to 23cm	3 to 20cm
LLD	19	2
Bone defect	12	in all 20
LLD + Bone defect	6	2
Bone grafting	All cases	4 cases
Union	All cases	All cases
Mean time for Healing	13.6 months	16.1 months
Limp	4	2
Equinus	5	3
Soft Tissue Dystrophy	4	2
Pain	4(persistent)	All (transient)
Neuro Vascular Complication	Nil	Nil
Amputation	1	0

Over all, there were 92% satisfactory bony and functional results in our series, as compared to 90% in Dror Paley's series.

Cattaneo R. et al[9] found application of circular fixator to diaphyseal infected non-union and segmental defects very encouraging. They used both internal transport and compression –distraction technique in the method. In our series only external transport technique was used with good results.

Song H.R. et al[33], recommended bone grafting at the docking site in order to shorten the duration of treatment to prevent re-fracture and non-union in 27 tibial bone defect cases. In this series only 4 cases needed bone grafting.

Hosny G. Sharoky MS[21] treated 11 patients with non-union and segmental defects of tibia with compression and distraction technique only. No additional procedures were used in any of their patients.in this series additional procedures like bone grafting, TA release, soft tissue release, extension of fixator in the form of foot assembly, hinges, long plate, translational assembly were needed to complete the treatment.

Yokoyama K. et al[38] attempted to discern the differences between free vascularised fibular grafts and callus distraction. They found that both the cost and functional outcomes between the two groups did not significantly differ other than a need of an expert in free fibular graft technique. Even though the defects were larger, we have not attempted free fibular graft in any of the cases.

J.Mahaluxmiwala et al[25] recommend acute shortening and then lengthening in segmental bone defects lesser than 6 cm as this method has the advantage of shorter treatment duration and lesser secondary procedures needed for bony union. In our series, most of the cases had bone loss of more than 6 cm. Hence, we have not attempted this method.

CONCLUSION

In the present scenario, the available solutions for large segmental long bone defects with or without shortening are external fixations like Ilizarov ring fixator or the dynamic axial fixator system. Of these two, Ilizarov method is cheaper and provides better all around stability as compared to the unilateral frame of dynamic axial fixator system.

- This can be used simultaneously for deformity correction and in conditions with poor skin with adherent scars on the deformed bone.
- Bone grafting is not necessary in all the cases.
- This system allows weight bearing during treatment period thus decreasing disuse osteoporosis and soft tissue dystrophy.

- The size of bone defect is not a limitation for reconstruction by distraction osteogenesis.

However there are certain disadvantages like bulky apparatus, prolonged treatment time, neurovascular complications, pin tract infections, muscle and joint contractures. Good compliance and cooperation from the patient is needed during the entire treatment period. The surgeon has a steep learning curve.

But if the established principles are strictly followed, then the **Ilizarov ring fixation and distraction osteogenesis** is the safest, simplest, most economical and effective method for the management of segmental long bone defects due to variety of causes.

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